

Prospects for EeV tau-neutrino physics with in-ice radio detectors

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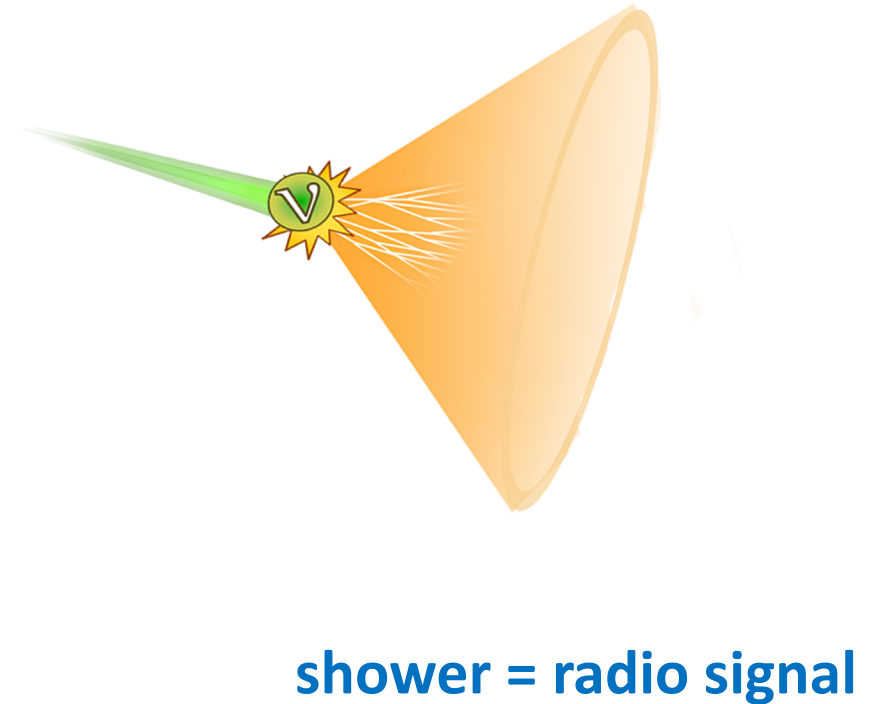
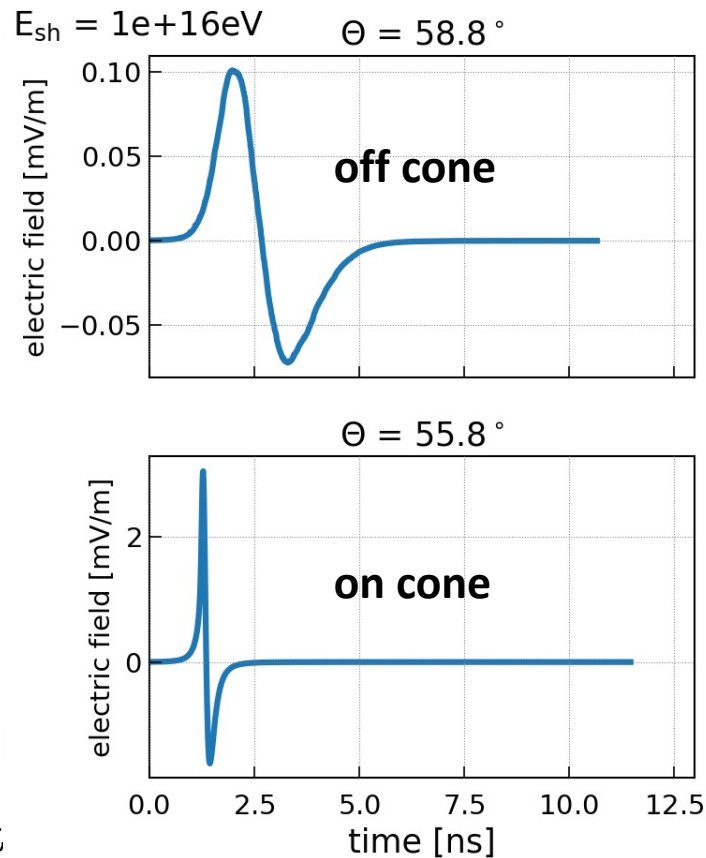
*based on Phys. Rev. D **102** 083011 (2020), and PoS(ICRC2021)1231*



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Detection principle of Askaryan radio detectors

- Askaryan effect: Time varying negative charge excess in the shower front
- Cherenkov-like time compression effect
- In ice: $\arccos(1/n) = 56$ deg



Experimental Landscape

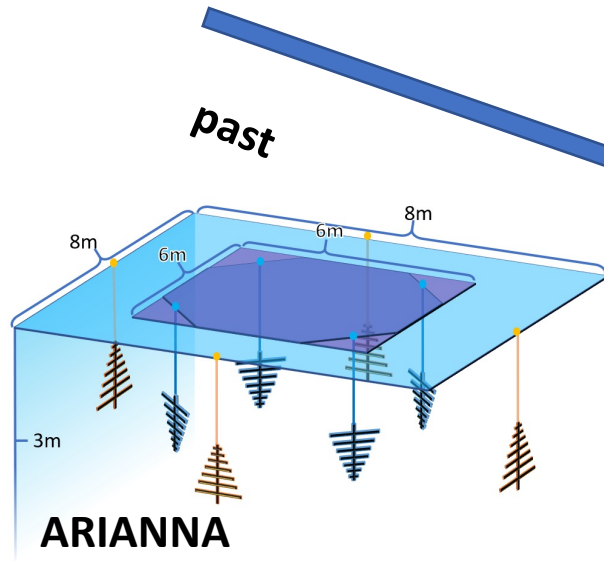
ARIANNA test bed

- 12 shallow stations at Moore's Bay + South Pole

ARA

- 5x 200m deep stations at South Pole

Radio technology developed and verified; hardware proven reliable

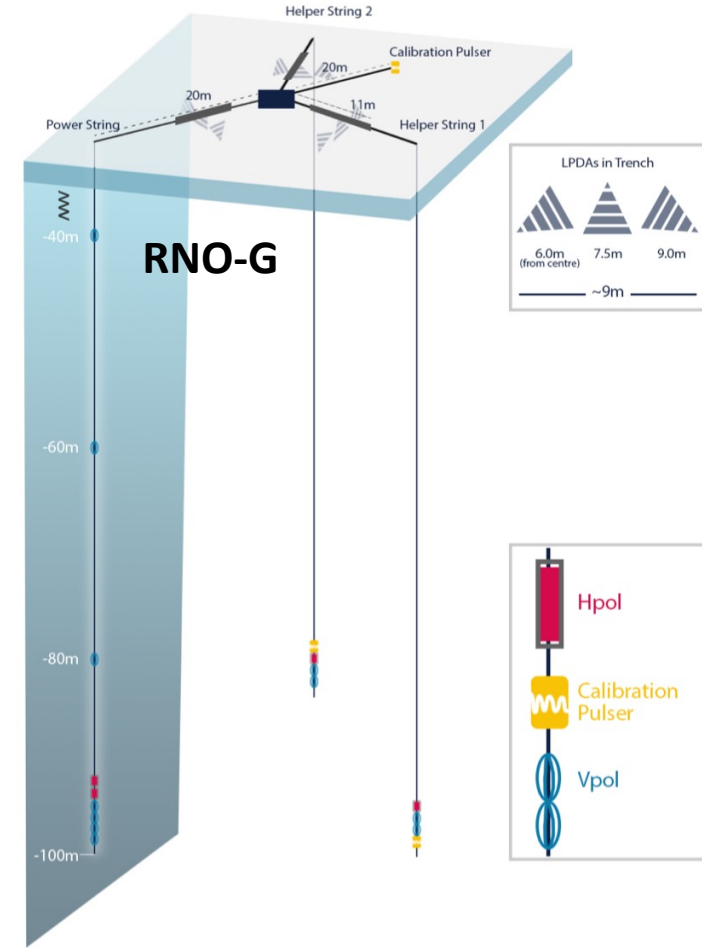


RNO-G

- 35 detector stations in Greenland
- first deployment summer 2021

ARIANNA-200 (proposed)

- 200 shallow detector stations at Moore's Bay

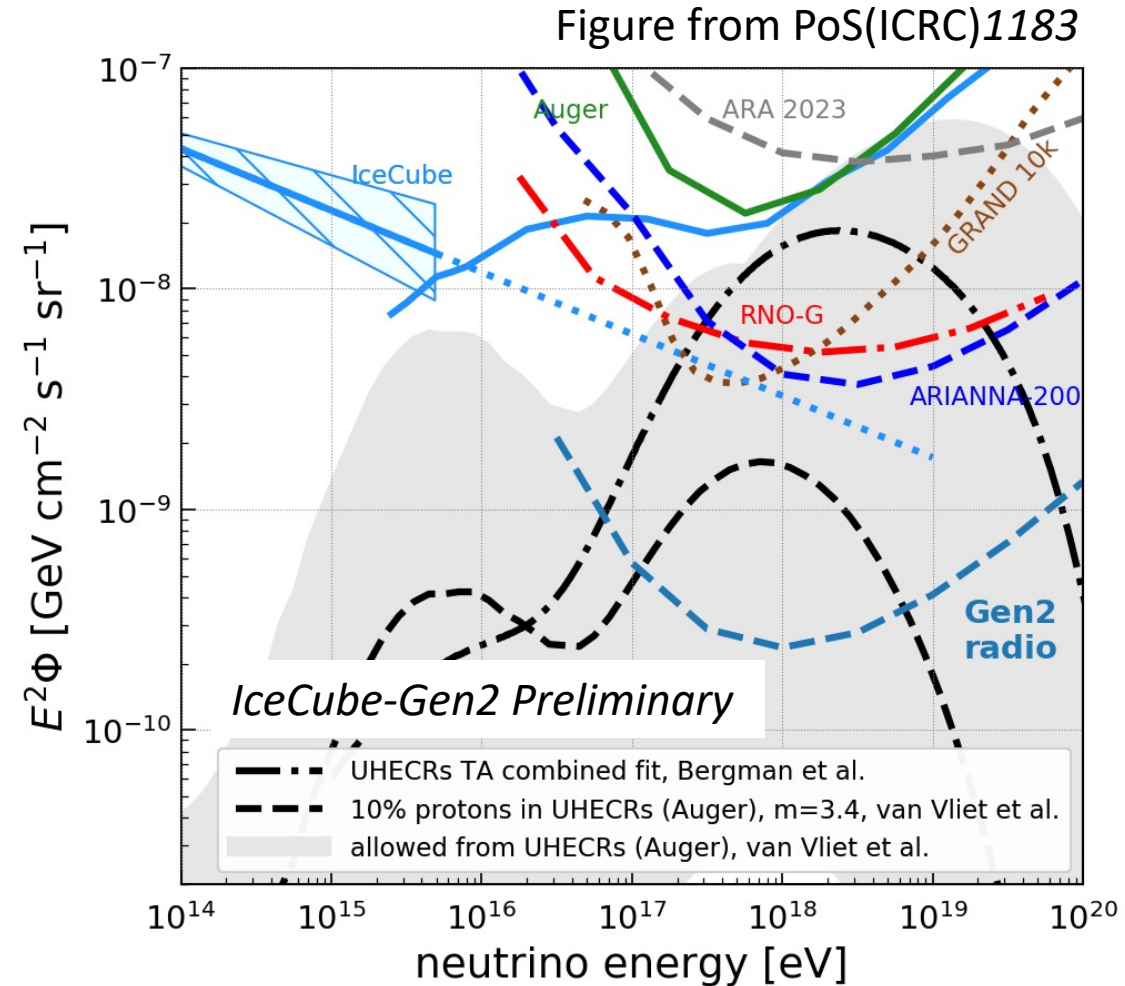


IceCube-Gen2

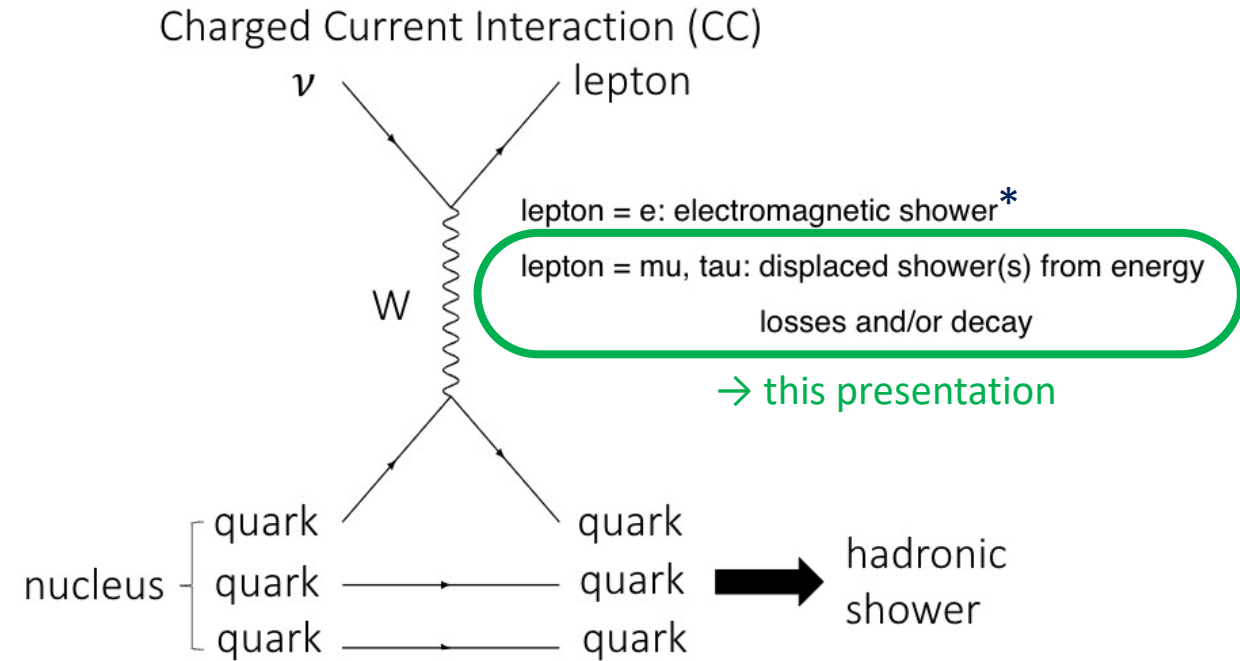
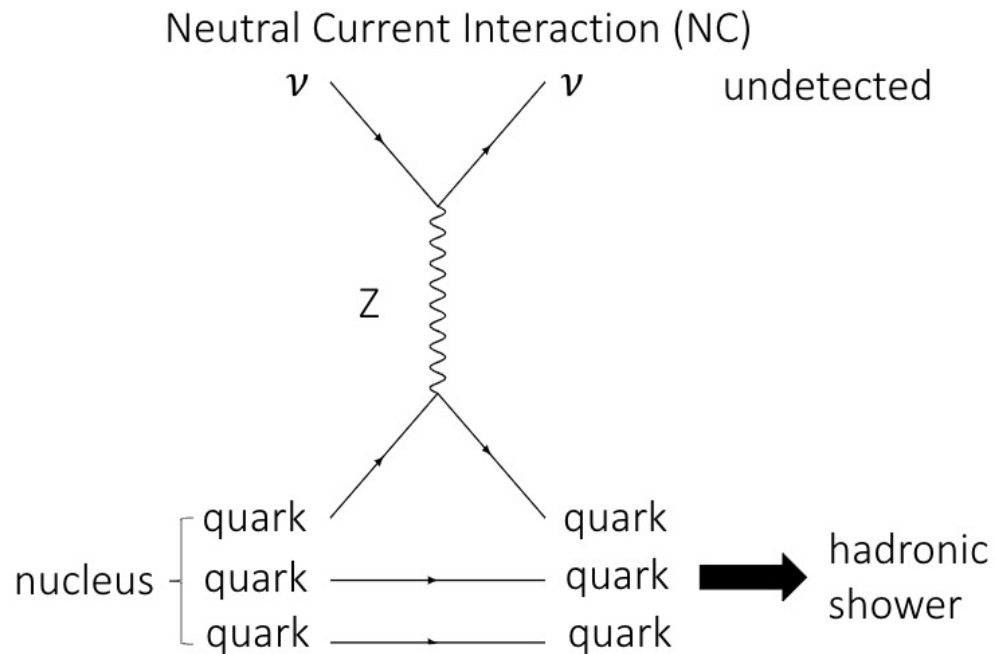
- 300+ detector stations at South Pole
- hybrid array of deep and shallow stations

Sensitivity of Radio Detectors

- In-ice radio detectors provide unprecedented sensitivity to EeV (10^{18} eV) neutrinos
- Discovery-size detectors underway
 - RNO-G in Greenland (under construction, *see e.g. PoS(ICRC2021)1058*)
 - ARIANNA-200 (proposed, *see e.g. PoS(ICRC2021)1190*)
- Large scale detector planned for IceCube-Gen2 (*see e.g. PoS(ICRC2021)1183*)



Neutrino interactions at EeV energies

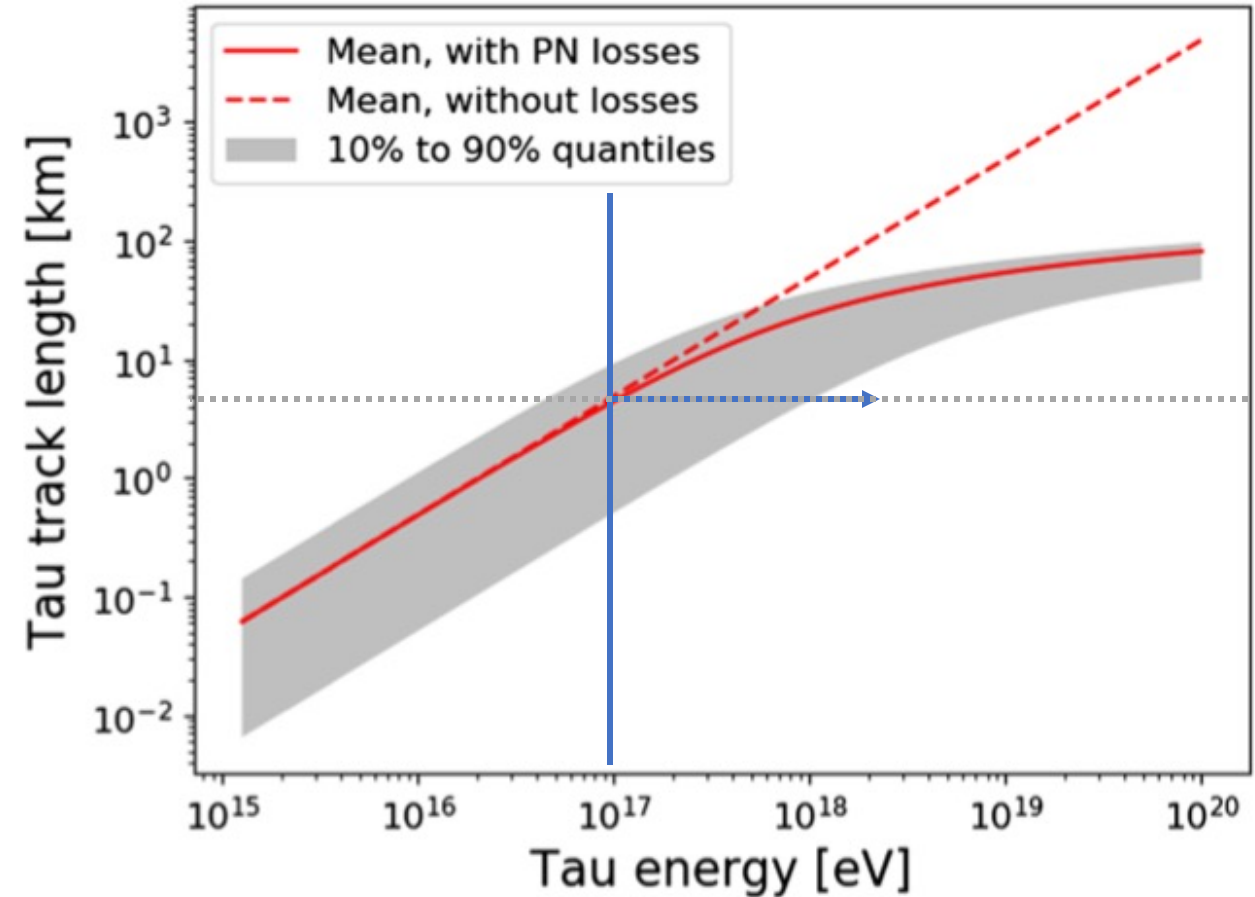


*: ν_e -CC interactions also provide flavor sensitivity due to the LPM effect, see PoS(ICRC2021)1055

Tau decay length

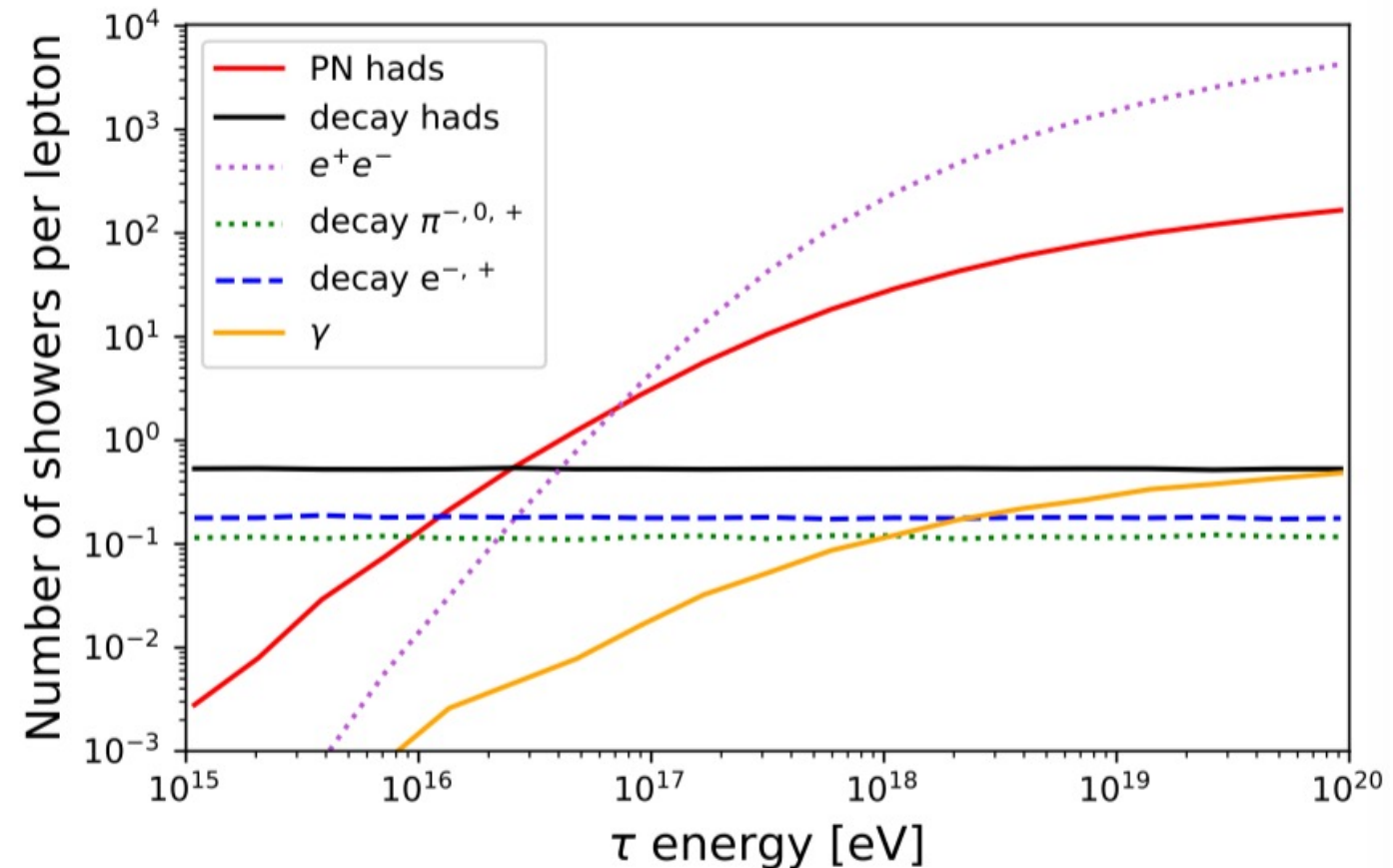
- At relevant energies for radio detection ($E > 10^{17}$ eV)
 - tau decay length several kilometers

from EPJ-C (2020) 80:77



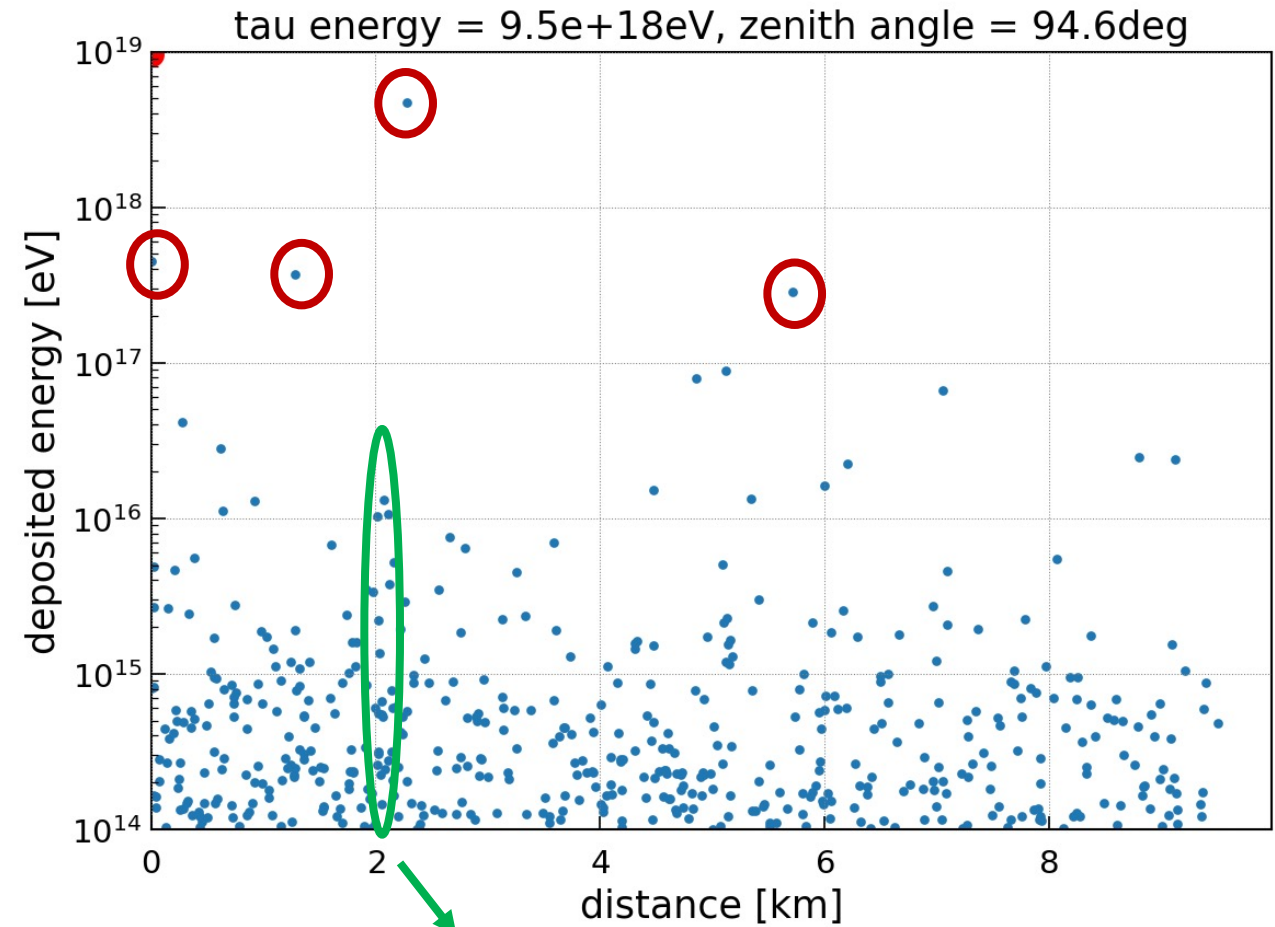
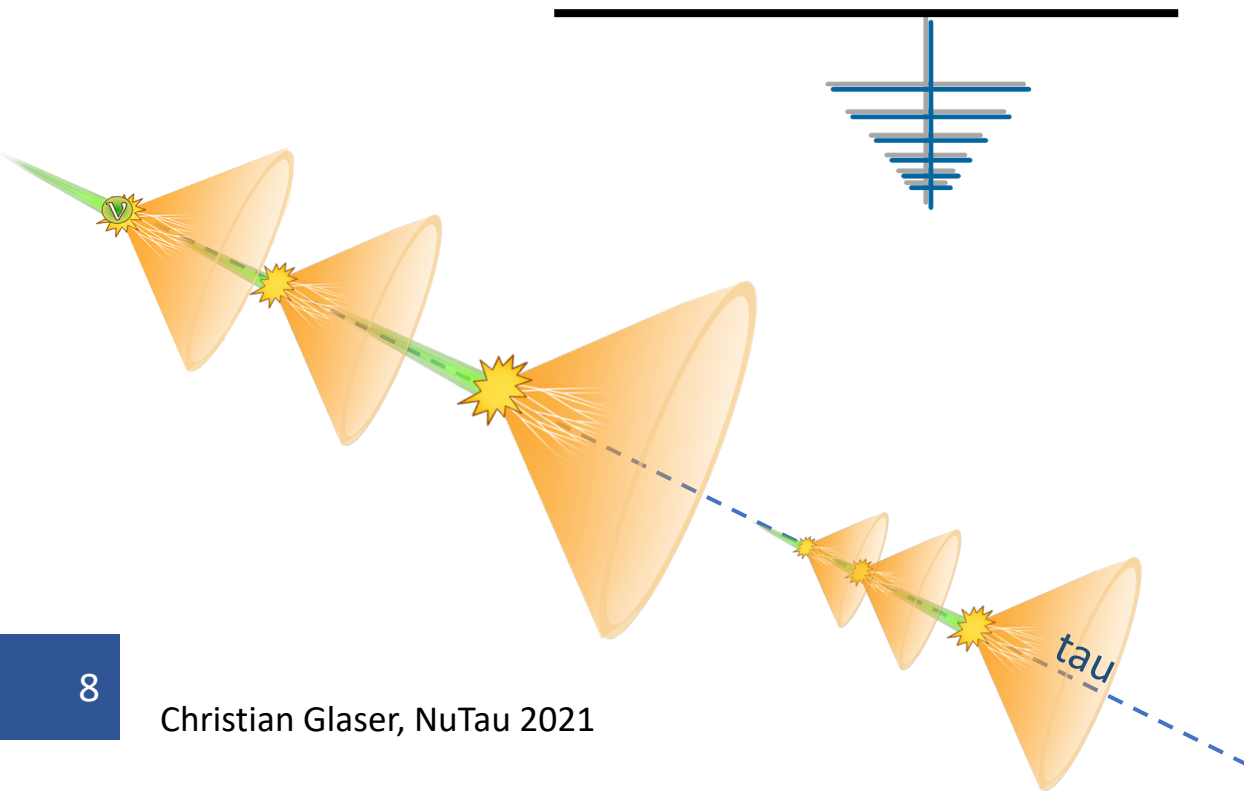
Tau interaction channels

- Tau propagation simulated using *PROPOSAL*, integrated into *NuRadioMC*
- Only counting showers $> 1\text{PeV}$
- Relevant interaction channels
 - decay (into hadrons, electrons, pions)
 - photonuclear interactions
 - pair production
 - Bremsstrahlung



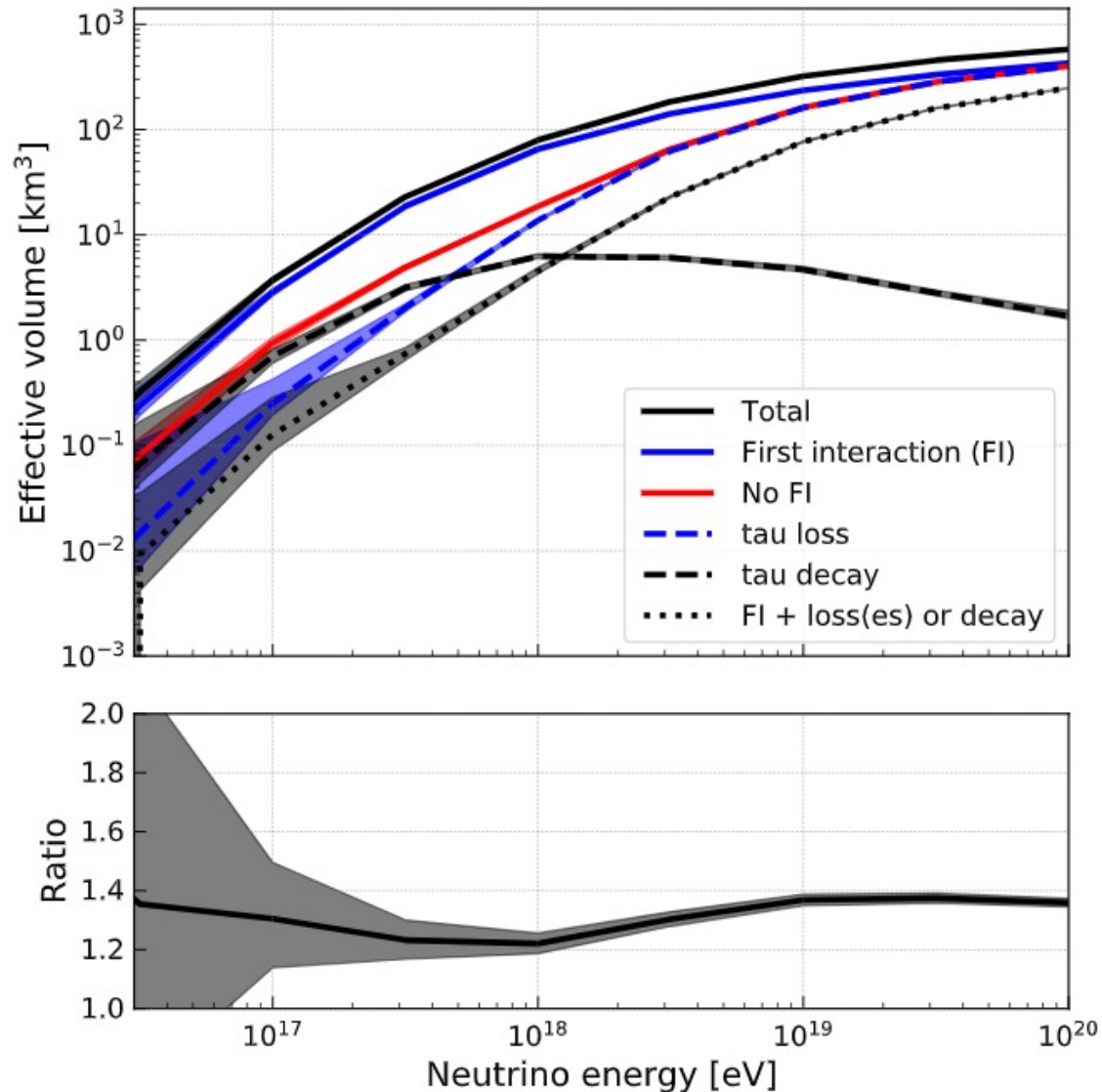
Energy losses of high-energy muon

- 1 EeV muon propagating through ice
- Simulated using *PROPOSAL*
- Stochastic energy losses $> 10^{14}$ eV shown



many low energy showers
might interfere constructively

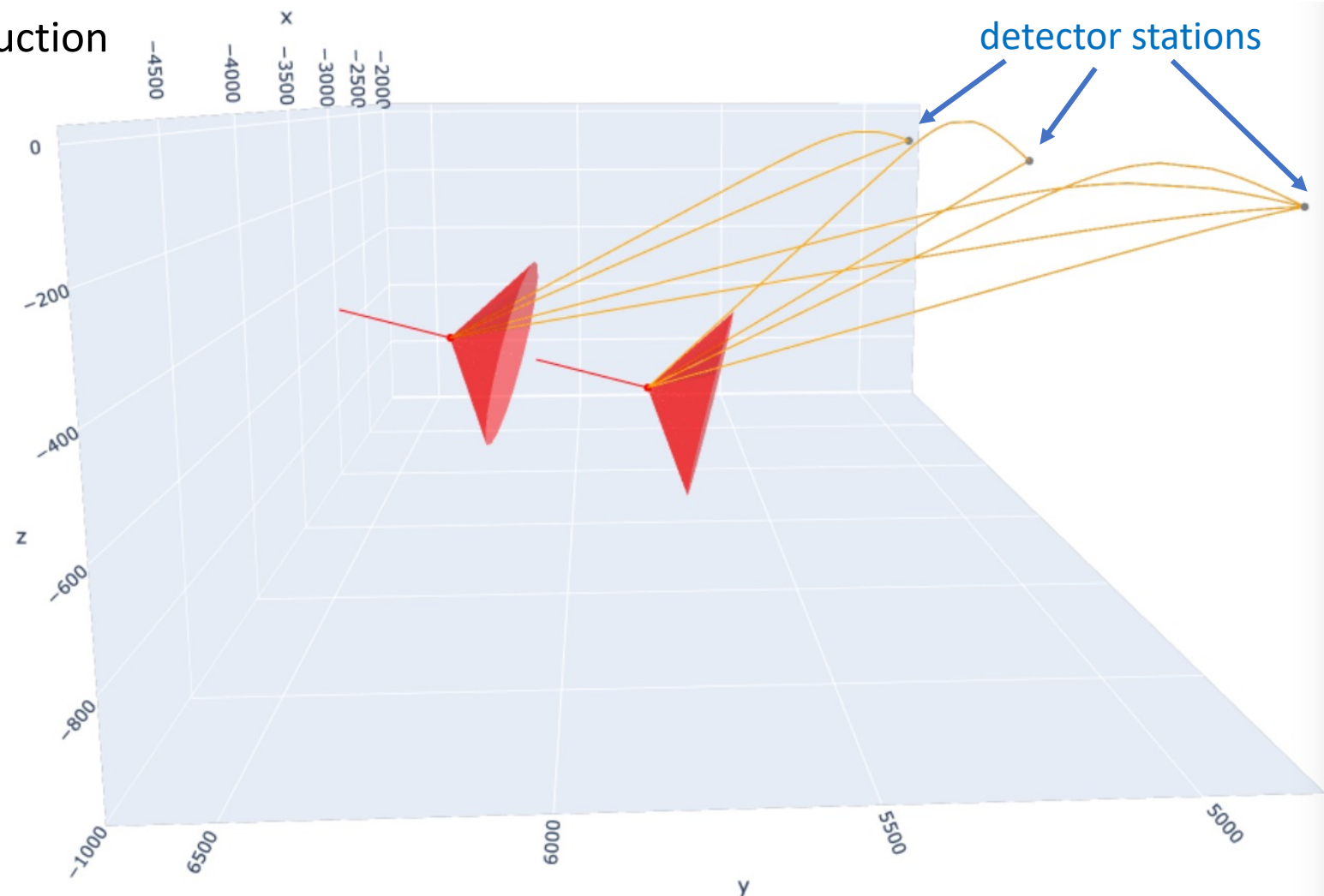
Tau neutrino effective volume



- Generic array with 2km spacing and 200m deep receivers at the **South Pole**
- Secondary interaction of taus increase sensitivity by up to 40%
 - at low energies tau decay channel dominates
 - $> 5 \times 10^{17} \text{ eV}$: tau energy losses dominate
- At high energies, many first and a secondary interaction detected simultaneously
 - flavor sensitivity

Golden event signature

- Simultaneous detection of first and secondary interaction
- Clear signature for muon or tau neutrino CC interactions
- Improved event reconstruction



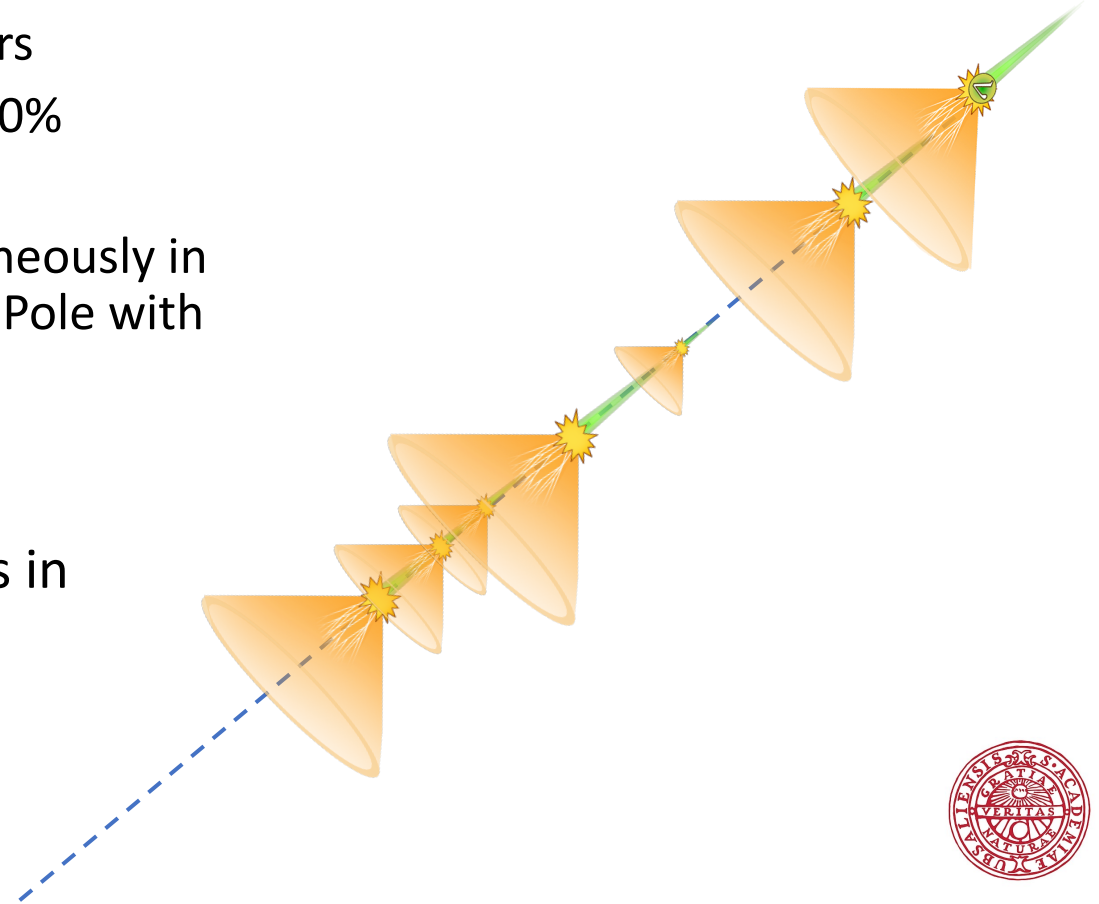
Summary

see also

Phys. Rev. D **102** 083011 (2020)

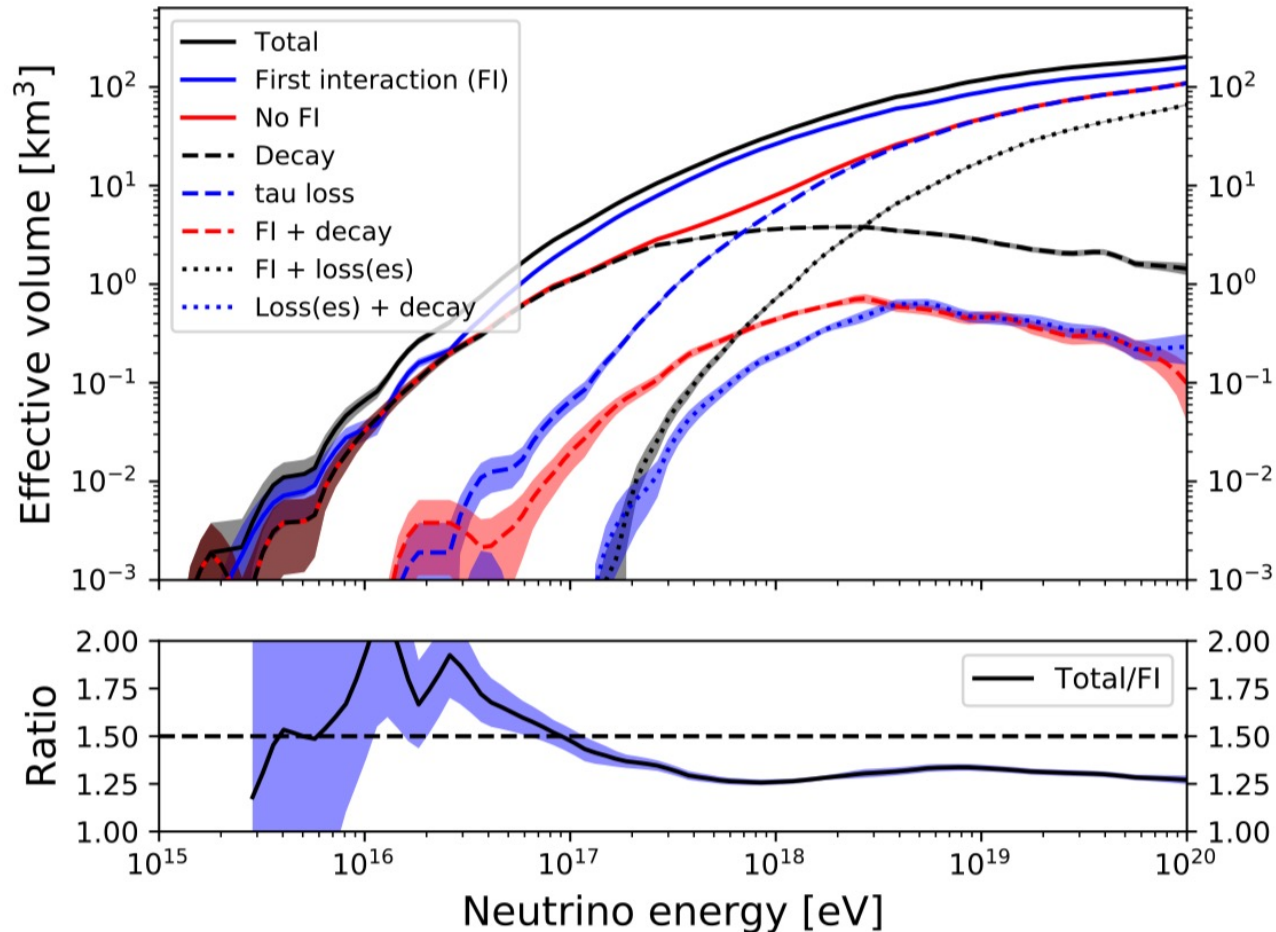
PoS(ICRC2021)1231

- Radio emission from secondary interactions of leptons integrated into NuRadioMC
- Taus (and muons) generated in neutrino CC interactions
 - generate visible signals in radio neutrino detectors
 - increase number of observable events by up to 40%
 - provide flavor sensitivity
 - first and secondary interaction observed simultaneously in 25% (τ)/50% (μ) at 10^{19} eV for array at the South Pole with 200m deep receivers and 2km spacing
 - Also flavor sensitivity from ν_e -CC interactions
(see PoS(ICRC21)1055)
- NuRadioMC generalized to calculate radio signals in detector for any number of in-ice showers
 - study of arbitrary emission scenarios



Backup

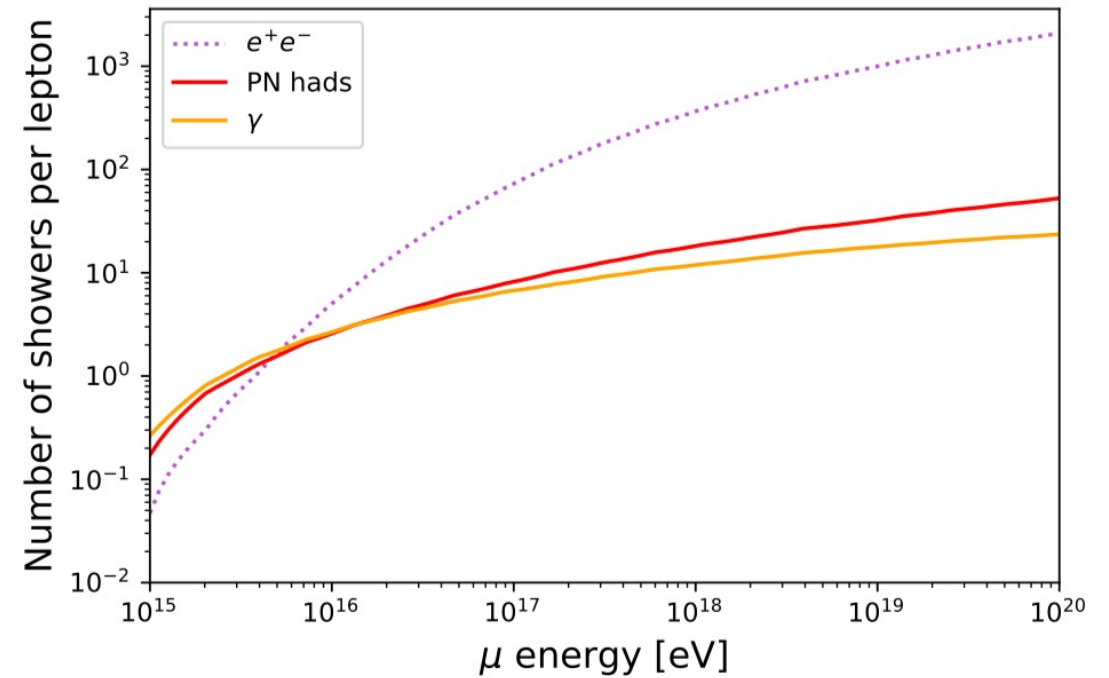
Tau neutrino effective volume



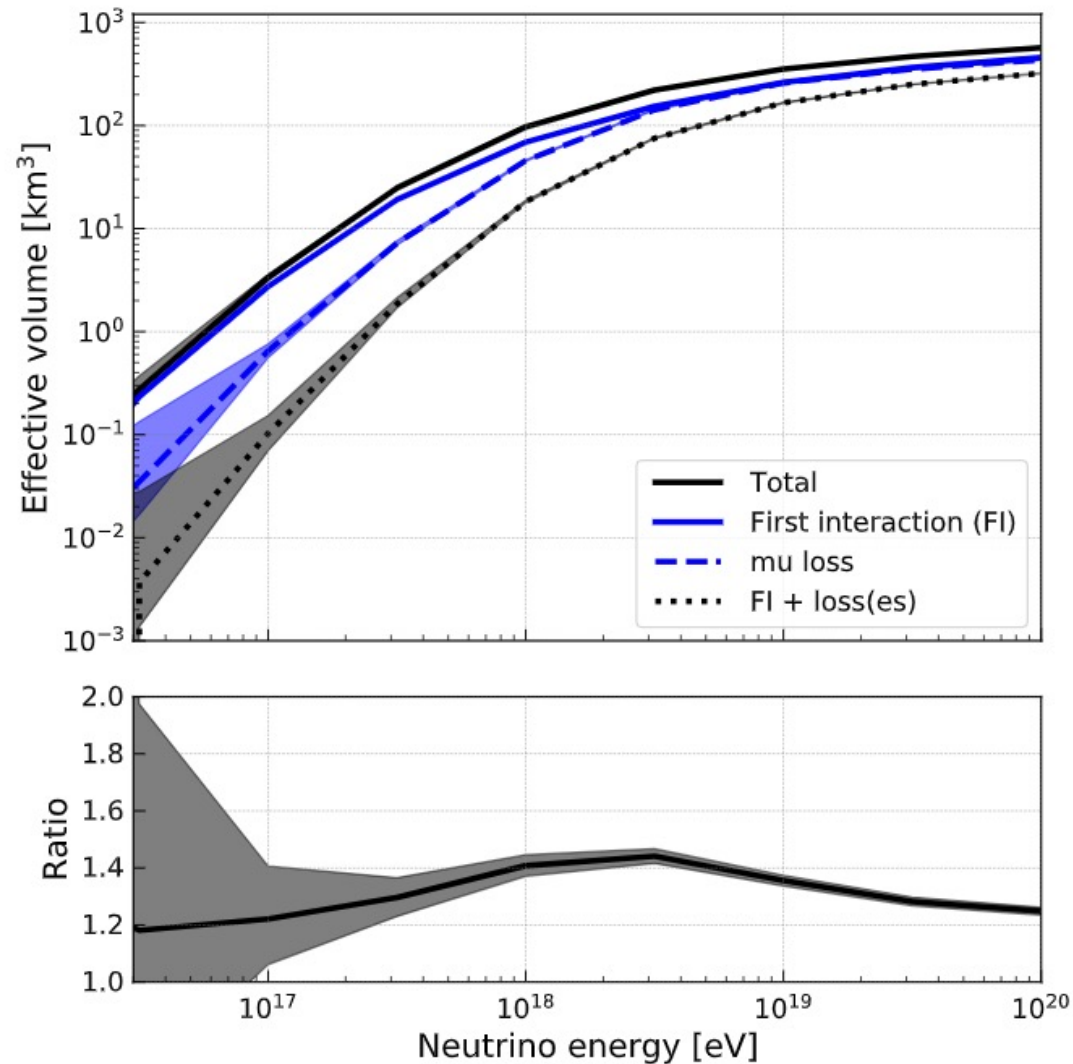
- Generic array with 1.25km spacing and 100m deep receivers in Greenland
- Secondary interaction of taus increase sensitivity by up to 25%
 - at low energies tau decay channel dominates
 - $> 5 \times 10^{17}$ eV: tau energy losses dominate
- At high energies, many first and a secondary interaction detected simultaneously
 - flavor sensitivity

Muon interaction channels

- Only counting showers $> 1\text{PeV}$
- Relevant interaction channels
 - pair production
 - Bremsstrahlung
 - photonuclear interactions



Muon neutrino effective volume



- Generic array with 2km spacing and 200m deep receivers at the **South Pole**
- Secondary interaction of muons increase sensitivity by up to 40%
- At high energies, first and a secondary interaction detected simultaneously

Atmospheric Muons

- High energy muons created in cosmic ray interactions induce in-ice showers
- Potential background, event rate uncertain due to flux uncertainties
- Using GSF cosmic ray model + SIBYLL2.3c -> 0.4 events/year for Gen2-radio (#1183)
- Also opportunity: Measurement of high-energy muon production

